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METHOD OF DETECTING MOTION IN AN INTERLACED VIDEO SEQUENCE UTILIZING REGION BY REGION MOTION INFORMATION AND APPARATUS FOR MOTION DETECTION

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METHOD OF DETECTING MOTION IN AN INTERLACED VIDEO SEQUENCE UTILIZING REGION BY REGION MOTION INFORMATION AND APPARATUS FOR MOTION DETECTION

BACKGROUND OF THE INVENTION

CROSS-REFERENCES TO RELATED APPLICATIONS

Applicant claims the benefit of U.S. Provisional Application No. 60/257,338 entitled "Methods of Detecting Motion in an Interlaced Video Sequence Based on Logical Operation on the Linearly Scaled Motion Information and the Apparatus Therefor," filed December 20, 2000, U.S. Provisional Application No. 60/257,365 entitled "Methods of Detecting Motion in an Interlaced Video Sequence Utilizing Region-Wise Motion and Apparatus" filed December 20, 2000, and U.S. Provisional Application No. 60/273,100 entitled "Method of Detecting Repetitive Motion In An Interlaced Video Sequence and Apparatus Therefor," filed March 2, 2001, which applications are incorporated herein by reference.

FIELD OF THE INVENTION

The invention lies in the signal processing field. More specifically, the invention pertains to a method of detecting motion in an interlaced video sequence. The invention is particularly applicable to the conversion of an interlaced

video signal to a progressive frame video signal, whereby regional motion information is utilized to define whether or not the video sequence contains motion or represents still image information. The invention also pertains to an apparatus for performing the method.

DESCRIPTION OF THE RELATED ART

In the development of current digital TV (DTV) systems, it is essential to employ a video format conversion unit because of the variety of the video formats adopted in many different DTV standards worldwide. For instance, the ATSC DTV standard system of the North America adopted 1080x1920 interlaced video, 720x1280 progressive video, 720x480 interlaced and progressive video, and so on, as its standard video formats for digital TV broadcasting. Video format conversion refers to a signal processing operation in which an incoming video format is converted to a specified output video format so that the output video can be properly displayed on a displaying device such as a monitor, FLCD, or a Plasma display, which has a fixed resolution.

Video format conversion systems are of significant importance since the conversion can directly affect the visual quality of the video of a DTV receiver. Fundamentally, the video format conversion operation requires

advanced algorithms for multi-rate system design, poly-phase filter design, and interlaced-to-progressive scanning rate conversion or simply deinterlacing. Deinterlacing represents an operation that doubles the vertical scanning rate of the interlaced video signal.

Interlaced video in general is a sequence of separately arriving fields, such as A1, A2, A3, etc., where A1, A2, and A3 are interlaced images with A1 being a top image, A2 being a bottom image, A3 being the next top image, and so on. The most popular systems currently in use, namely NTSC, PAL, and SECAM are two-field systems, where two consecutive fields (such as the top field A1 and the bottom field A2) make up a frame. Each scanned field contains, i.e., updates, every other line of a corresponding frame and the number of lines in the frame is twice the number of lines in each of the fields. Typically, the first field of a frame is identified with odd-numbered lines and the second field is identified with even-numbered lines. The fields are scanned onto the display screen one after the other at a defined frequency.

By way of example, NTSC scans close to 30 frames (60 fields of interlaced video) per second, with 525 lines per frame, and a horizontal to vertical aspect ratio of 4:3. The frame difference, therefore, is the difference between two

fields having the same types (top or bottom) such as A1 and A3, or A2 and A4. PAL and SECAM scan 25 frames per second, with 625 lines per image, and the same aspect ratio of 4:3. As noted, the interlacing in all of these systems is 2:1, i.e., two fields per one frame. The primary reason for the interlacing of the lines between the fields is to reduce flicker in the display. An image that is updated, say, only 30 times a second would allow the human eye to perceive the scanning, because the image information would already start to fade before the next image is scanned onto the screen. When two fields are used, and each contains half of the information, the scanning rate in effect is raised to 60 Hz, and the human eye no longer perceives any flicker.

Deinterlacing refers to the filling of unavailable lines in each of the fields A1, A2, A3, and so on. As a result of deinterlacing, a 60 Hz field sequence (of interlaced video fields) becomes a 60 Hz progressive sequence.

Interlaced video is subject to several intrinsic drawbacks, referred to as artifacts. These include serrated lines that are observed when there is motion between fields, line flickering, raster line visibility, and field flickering. These also apply to DTV (digital TV) receivers. Historically, deinterlacing algorithms have been developed to

enhance the video quality of NTSC TV receivers by reducing these intrinsic annoying artifacts of the interlaced video signal. Besides, elaborate deinterlacing algorithms utilizing motion detection or motion compensation provide excellent methods of doubling the vertical scanning rate of the interlaced video signal especially for stationary (motionless) objects in the video signal.

The present invention therefore also relates to the motion detection based deinterlacing operation that can be used for analog and digital TV receivers.

The state of the art includes a variety of deinterlacing algorithms, each having been exploited and studied comprehensively by many researchers during the last decade. Deinterlacing algorithms can be categorized into two classes, namely, 2-D(spatial) deinterlacing algorithms and 3-D (spatio-temporal) deinterlacing algorithms depending on the use of motion information embedded in consecutive interlaced video sequence. Combined spatial and temporal 3-D deinterlacing algorithms based on a motion detection give more pleasing performance than 2-D deinterlacing algorithms. The key point of a 3-D deinterlacing algorithm is how to precisely detect motion in the interlaced video signals. The publications in the following list disclose some of the

applicable deinterlacing methods. They may be categorized as follows:

[1] Simple line doubling scheme, vertical filtering, vertical edge controlled interpolation method disclosed in the IEEE Transactions on Consumers Electronics, pp. 279-89, August 1989 by D.I. Hentschei;

[2] Edge direction dependent deinterlacing method disclosed in the Proc. of the Int. Workshop on HDTV, 1994, by D. Bagni, R Lancini, and S. Tubaro;

[3] Nonlinear interpolation methods based on:

a weighted median filter disclosed in the Proc. of the IEEE ISCAS, pp. 433-36, Portland, USA, May 1989, by J. Juhola, A. Nieminen, J. Sal, and Y. Neuvo,

FIR median hybrid interpolation disclosed in Pro. Of SPIE's Visual Communications and Image Processing, Lausanne, Switzerland, October 1990, 00. 125-32 by A. Lehtonen and M. Renfors,

a complementary median filter disclosed in Proc. of the Int. Workshop on HDTV, 1994 by H. Blume, I. Schwoerer, and K. Zygis,

[4] A motion adaptive method disclosed in IEEE Transactions on Consumer Electronics, pp. 110-114, May 1990 by C. Markhauser.

More recently, a new motion detection based deinterlacing method has been described in the following two patents:

[5] U.S. Patent No. 5,943,099, Aug. 24, 1999, to Young-Taek Kim, entitled Interlaced-to-Progressive Conversion Apparatus and Method Using Motion and Spatial Correlation. There, an interlaced-to-progressive conversion device includes a spatial interpolator that provides for spatial interpolation and a temporal interpolator that provides for temporal interpolation of an interlaced video input signal. The system reduces jitter and related artifacts by temporally or spatially interpolating the signals.

[6] U.S. Patent No. 5,959,681, Sep. 28, 1999, to Yong-Hun Cho, entitled Motion Picture Detecting Method. There, two separate field memories are utilized for detecting rapid

motion and slow motion in an interlaced video sequence. An interlaced video signal is thereby converted into a progressive-scanned signal. Differences between spatial interpolation and temporal interpolation are used to determine whether the image is in motion. If the differences exceed certain defined thresholds, motion is determined. The thresholds are dynamically adapted during the process.

The core of the methods described in the latter two patents is to estimate a motion decision factor based on the frame difference signal and the sample correlation in the vertical direction. These methods provide a way of reducing the visual artifacts that can be possibly arising from false motion detection by utilizing the sample correlation in vertical direction of the sampling point where the value is to be interpolated. A common drawback of those methods, however, is that they do not provide a true motion detection method when there are high frequency components in the vertical direction. In other words, when there are high frequency components in the vertical direction, the methods described in the references [5] and [6] will come to the conclusion that motion pictures are processed.

As a consequence, in many instances, those prior art processing methods do not provide for an increase in the

vertical resolution even when no real motion is present between fields.

SUMMARY OF THE INVENTION

It is accordingly an object of the invention to provide a motion detection method in interlaced video, which overcomes the above-mentioned disadvantages of the heretofore-known devices and methods of this general type and which provides for a robust method of estimating a motion decision parameter which is associated with the point to point degree of motion in the interlaced video sequence. It is another object of the present invention to disclose a deinterlacing method and apparatus by utilizing the motion decision parameter of the invention.

With the foregoing and other objects in view there is provided, in accordance with the invention, a method of computing a motion decision value for further utilization in a video signal processing system. The method comprises the following steps:

inputting a video signal with an interlaced video sequence;

computing a frame difference signal from a difference between the previous field and the next (following) field of the field to be deinterlaced;

forming a point-wise motion detection signal from the frame difference signal;

computing a region-wise motion detection signal from the point-wise motion detection signal and an adjacent point-wise motion detection signal delayed by one field; and

forming from the region-wise motion detection signal a motion decision value and outputting the motion decision value for further processing in the video signal processing system.

In accordance with an added feature of the invention, the difference signal is low-pass filtered prior to the step of forming the point-wise motion detection signal.

In accordance with an additional feature of the invention, low-pass filter is defined by the matrix

$$W_{MxN} = \begin{bmatrix} w_{11} & w_{12} & \cdots & w_{1N} \\ w_{21} & w_{22} & \cdots & w_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ w_{M1} & w_{M2} & \cdots & w_{MN} \end{bmatrix}$$

where w_{11}, . . . w_{MN} represent a set of predetermined coefficients.

In accordance with a further feature of the invention, the point-wise motion detection signal is formed according to the formula

$$f_n(i,h) = T_K(d_n(i,h))$$

where f_n is the point-wise motion detection signal, i and h define a spatial location of the respective video signal value in a cartesian matrix, $T_K(\cdot)$ denotes a threshold function represented as

$$T_K(y) = \left\{ \begin{array}{lll} 1, & if & y \geq K \\ 0, & & otherwise \end{array} \right\}$$

in which K is a positive constant, and $d_n(\ )$ is the low-pass filtered frame difference signal.

In accordance with another feature of the invention, the region-wise motion detection signal is computed from the point-wise motion detection signal by logically combining the point-wise motion detection signal f_n as

$$\phi_n(i,h) = f_n(i,h) \| f_{n-1}(i-1,h) \| f_{n-1}(i+1,h)$$

where $f_{n-1}(\cdot)$ denotes the motion detection signal delayed by one field, the indices i and h define a spatial location of the respective video signal value in a cartesian matrix, and the notation 11 denotes a logical OR operation.

In accordance with again an added feature of the invention, the region-wise motion detection signal is low-pass filtered prior to outputting it. In a preferred embodiment, the region-wise motion detection signal is low-pass filtered to form the motion decision value $m_n(i,h)$ by:

$$m_n(i,h) = \sum_{p=-a}^{b} \sum_{q=-c}^{d} \phi_n(i+2\times p, h+2\times q)\cdot \alpha_{p,q}$$

where a,b,c,d ≥ 0, and $\alpha_{p,q}$ represents a set of normalized predetermined coefficients of a low pass filter. Preferably, the kernel of the low pass filter is defined by

$$\left[\alpha_{p,q}'s\right]=\begin{bmatrix}0 & 1/8 & 0\\ 1/8 & 4/8 & 1/8\\ 0 & 1/8 & 0\end{bmatrix}.$$

With the above and other objects in view there is also provided, in accordance with the invention, a method of processing interlaced video signals, which comprises:

spatially interpolating a value of the video signal at a given location from a video signal of a given video field;

temporally interpolating the value of the video signal at the given location from a video signal at the same location in temporally adjacent video fields; and

forming a motion decision value for the same location in accordance with the above-summarized method; and

mixing an output signal for the video signal at the given location from the spatially interpolated signal and the temporally interpolated signal and weighting the output signal in accordance with the motion decision value.

In a preferred embodiment of the invention, the motion decision value is varied between 0 and 1 as a function of an estimate of the degree of motion at the given location and, upon estimating a high degree of motion, the output signal is heavily weighted towards the spatially interpolated signal and, upon estimating a low degree of motion, the output signal is heavily weighted towards the temporally interpolated signal.

In accordance with a specific embodiment of the invention, the temporally interpolated signal is output as the output signal upon estimating a low degree of motion, and the spatially interpolated signal is output as the output signal upon estimating a high degree of motion.

There is also provided, in accordance with the invention, an apparatus for computing a motion decision value in accordance with the above-outlined process. The novel apparatus comprises:

an input for receiving a video signal with an interlaced video sequence;

difference forming means connected to the input for computing a frame difference signal from a difference between the previous field and the next field;

means for forming a point-wise motion detection signal from the frame difference signal, and for computing a region-wise motion detection signal from the point-wise motion detection signal and an adjacent point-wise motion detection signal delayed by one field; and

means for forming from the region-wise motion detection signal a motion decision value and for outputting the motion decision value for further processing in the video signal processing system.

In accordance with yet an added feature of the invention, the apparatus has a logic member programmed to compute the motion decision value from the point-wise motion detection signal by logically combining the point-wise motion detection signal f_n as

$$\phi_n(i,h) = f_n(i,h) \| f_{n-1}(i-1,h) \| f_{n-1}(i+1,h)$$

where $f_{n-1}(\cdot)$ denotes the motion detection signal delayed by one field, the indices i and h define a spatial location of the respective video signal value in a cartesian matrix, and the notation 11 denotes a logical OR operation.

Finally, there is provided, in accordance with the invention, an apparatus of processing interlaced video signals, for example in an interlaced to progressive conversion, which comprises:

an input for receiving a video signal with an interlaced video sequence of fields;

a spatial interpolator connected to the input and configured to spatially interpolate a value of the video signal at a given location from a video signal of at least one adjacent location in a given video field;

a temporal interpolator connected to the input in parallel with the spatial interpolator for temporally interpolating the value of the video signal at the given location from a video signal at the same location in temporally adjacent video fields; and

a computing apparatus according to the above-outlined invention connected to the input and in parallel with the spatial interpolator and the temporal interpolator for forming a motion decision value for the same location; and

a mixer connected to receive an output signal from each of the spatial interpolator, the temporal

interpolator, and the computing apparatus, the mixer being configured to mix an output signal for the video signal at the given location from the spatially interpolated signal and the temporally interpolated signal in dependence on the motion decision value output by the computing apparatus.

Other features which are considered as characteristic for the invention are set forth in the appended claims.

Although the invention is illustrated and described herein as embodied in a method of detecting motion in an interlaced video sequence and an apparatus therefor, it is nevertheless not intended to be limited to the details shown, since various modifications and structural changes may be made therein without departing from the spirit of the invention and within the scope and range of equivalents of the claims.

The construction of the invention, however, together with additional objects and advantages thereof will be best understood from the following description of the specific embodiment when read in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWING

Fig. 1 is a diagrammatic view of two juxtaposed fields of a frame of an interlaced video sequence;

Fig. 2 is a diagrammatic illustration of three fields serving to describe the deinterlacing problem;

Fig. 3 is a more detailed view illustrating the deinterlacing process;

Fig. 4 is a block diagram illustrating the computation of a motion decision parameter; and

Fig. 5 is a block diagram showing the computation of the motion decision parameter and the resultant mixing of the spatially and temporally interpolated signals in dependence on the motion decision.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the figures of the drawing in detail and first, particularly, to the introductory view of Fig. 1, an interlaced video sequence is a series of frames each including a plurality of fields. As noted above, all conventional systems utilize two fields per frame which are sequentially scanned. A top field 1 contains information

regarding the first ($v = 0$), third ($v = 2$), fifth ($v = 4$), etc. lines, and a bottom field 2 contains information regarding the second ($v = 1$), fourth ($v = 3$), sixth ($v = 5$), etc. lines.

In order to systematically describe the deinterlacing problem and the methods of the present invention, let x_n denote the incoming interlaced video field at a time instant $t = n$ and x_n (v,h) denote the associated value of the video signal at the geometrical location (v,h). The variable v represents the vertical location and h represents horizontal location, in the cartesian matrix system commonly applied. By definition, the signal values of x_n of the interlaced video signal are available only for the even lines ($v = 0,2,4,...$) if x_n is the top field 1. Similarly, the signal values of x_n are available only for the odd lines of v ($v = 1,3,5,...$) if x_n is the bottom field 2. Conversely, the signal values of x_n are not available for odd lines if x_n is a top field signal and the signal values of x_n are not available for even lines if x_n a bottom field. Fig. 1 shows the top field 1 scanned at $t = m$ and the bottom field 2 scanned at $t = m + 1$. Top and bottom fields are typically available in turn in the time axis, that is, the top and bottom fields are sequentially scanned to make up a frame.

Based upon the description of the interlaced video signal, deinterlacing problem can be stated as a process to reconstruct or interpolate the non-available signal values of each field. That is, the deinterlacing problem is to reconstruct the signal values of x_n at the odd lines (v = 1,3,5,...) for the top field x_n and to reconstruct the signal values of x_n at the even lines (v = 0,2,4,...) for the bottom field x_n.

For the simple description of the present invention, and to avoid any notational confusion in the disclosure, the deinterlacing problem will be simplified as a process which reconstructs or interpolates the unavailable signal value of x_n at the i^{th} line where the signal values of the lines at i±1, i±3, i±5,... are available. More simply deinterlacing is to interpolate the value of $x_n(i,h)$, which is not originally available. It must be noted that, since x_{n-1} and x_{n+1} have a different sampling phase from x_n, the signal values of $x_{n-1}(i,h)$ and $x_{n+1}(i,h)$ are available, which is why motion detection can be incorporated with the deinterlacing problem. This relationship is depicted in Fig. 2, where dotted lines (and white circles) represent "no data available" and solid lines (and black circles) represent "available data."

The deinterlacing method and an exemplary apparatus of the present invention with preferred embodiments will be better understood from the following description, which will make specific reference to Figs. 3-5 of the drawing.

Referring now to Fig. 4, there is illustrated the novel method of estimating a motion decision parameter $m_n(i,h)$. Fundamentally, $m_n(i,h)$ is estimated from the incoming interlaced video sequence and associated with the point-to-point degree of motion in the interlaced video sequence. The importance or the usefulness of estimating $m_n(i,h)$ can be easily understood from Figs. 2 and 3. Suppose that precise motion detection information is available when we interpolate $x_n(i,h)$ and suppose there is no motion at the spatial location (i,h), then the best interpolation for $x_n(i,h)$ is to use the value of $x_{n-1}(i,h)$. This follows logically from the fact that no motion is introduced between $t = n - 1$ and $t = n + 1$ at the spatial location (i,h), which very strongly implies that the value of $x_n(i,h)$ would be close to the value of $x_{n-1}(i,h)$. The usage of the motion decision parameter of the present invention is also to utilize the motion information for deinterlacing to properly mix the temporal information, which will be described later.

First, the frame difference signal D_n is computed by taking the difference between the fields in one frame interval as

$$D_n = |x_{n+1} - x_{n-1}|$$

which associates with the scene change that occurred between the fields x_{n+1} and x_{n-1}. The frame difference signal is then low pass filtered to form

$$d_n = LPF(D_n)$$

where LPF(·) represents a low pass filtering process over the input video signal. The M x N kernel, W_{MxN}, in general, of the low pass filter LPF(·), can be expressed as

$$W_{MxN} = \begin{bmatrix} w_{11} & w_{12} & \cdots & w_{1N} \\ w_{21} & w_{22} & \cdots & w_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ w_{M1} & w_{M2} & \cdots & w_{MN} \end{bmatrix}$$

where (w_{11}, …, w_{MN}) represents a set of predetermined coefficients. It should be mentioned that the characteristic of the LPF (·) can be all-pass filter depending on the choice of the kernel W_{MxN}. That is, if the kernel is set as M = N =

1, and w_{11}=1, the LPF(·) becomes an all-pass filter and, thus, $d_n = D_n$.

Next, a point-wise motion detection signal is computed as

$$f_n(i,h) = T_K(d_n(i,h)) \tag{1}$$

where $T_K(\cdot)$ denotes a threshold function represented as

$$T_K(y) = \begin{Bmatrix} 1, & if & y \geq K \\ 0, & & otherwise \end{Bmatrix}$$

in which K is a positive constant value. Then the region-wise motion detection signal is computed from the point-wise motion detection signal which logically combines the signals f as

$$\phi_n(i,h) = f_n(i,h) \| f_{n-1}(i-1,h) \| f_{n-1}(i+1,h)$$

where $f_{n-1}(\cdot)$ denotes the one field delayed motion detection signal described in (1) and where the notation 11 denotes the logical OR operation.

Finally, the region-wise motion detection signal is low-pass filtered and the filtered signal now forms the motion decision parameter $m_n(i,h)$, namely:

$$m_n(i,h) = \sum_{p=-a}^{b} \sum_{q=-c}^{d} \phi_n(i+2\times p, h+2\times q)\cdot \alpha_{p,q} \qquad (2)$$

where a,b,c,d ≥ 0, and $\alpha_{p,q}$ represents a set of normalized $(i.e., \sum_{p=-a}^{b} \sum_{q=-c}^{d} a_{p,q} = 1)$ predetermined coefficients of a low pass filter. For instance, the kernel of the low pass filter used in (2) can be

$$[\alpha_{p,q}'s] = \begin{bmatrix} 0 & 1/8 & 0 \\ 1/8 & 4/8 & 1/8 \\ 0 & 1/8 & 0 \end{bmatrix}$$

The diagram of Fig. 4 illustrates the computation of the motion decision parameter $m_n(i,h)$ as described above. The computed motion decision parameter $m_n(i,h)$ is then used to mix a spatially interpolated signal and a temporally interpolated signal, as illustrated further in Fig. 5.

Fig. 5 illustrates a block diagram of an embodiment of the present invention for interpolating the value of $x_n(i,h)$ for an interlaced video sequence. The apparatus comprises a

spatial interpolator 3, a temporal interpolator 4, a motion decision processor 5, and a mixer 6. The decision processor 5 corresponds to the diagram illustrated in Fig. 4 and includes, in a signal flow direction, an absolute value former 51 which defines the absolute difference parameter D_n; a first low pass filter LPF 52 in which the filtering function W_{MxN} with the MxN kernel is set; an adjustable or fixed threshold member 53 which, in a preferred embodiment, is implemented as a controlled comparator; a buffer memory 54 and a further line memory 55 are connected to an OR logic 56 in which the function signal $\phi_n(i,h)$ is formed as described above; finally, the motion detection signal $m_n(i,h)$ is formed by low pass filtering in a spatial low pass filter LPF 57. The output of the low pass filter 57 is connected so that the motion detection signal $m_n(i,h)$ is supplied to a control input of the mixer 6.

The spatial interpolator 3 spatially interpolates the value of $x_n(i,h)$ by using a predetermined algorithm. The temporal interpolator 4 temporally interpolates the value of $x_n(i,h)$ by using a predetermined algorithm. The motion decision value $m_n(i,h)$ computed in the motion decision processor 5, as disclosed in the above, represents the degree of the motion at the interpolation location (i,h). Conceptually, the value of the motion decision parameter will

be bounded as $0 \le m_n(i,h) \le 1$ where the extreme $m_n(i,h) = 0$ implies "no motion" and $m_n(i,h) = 1$ implies "motion". The mixer mixes the output signal of the spatial interpolator and the output signal of the temporal interpolator in accordance with the motion decision value. Letting $x_n^s(i,h)$ and $x_n^t(i,h)$ as the output signal of the spatial interpolator and the output signal of the temporal interpolator, respectively, the output signal of the mixer, or, the interpolated signal is represented as

$$x_n(i,h) = (1 - m_n(i,h)) \cdot x_n^t(i,h) + m_n(i,h) \cdot x_n^s(i,h)$$

It is clear that $x_n(i,h) = x_n^t(i,h)$ when $m_n(i,h) = 0$ (no motion) and $x_n(i,h) = x_n^s(v,h)$ when $m_n(i,h) = 1$ (motion).

It will be understood that it does not matter what kind of spatial interpolating algorithm (in the spatial interpolator 3) and what kind of temporal interpolating algorithm (in the temporal interpolator 4) are used for the interpolation. The present invention is only concerned with estimating the motion decision value $m_n(i,h)$ and with mixing a spatially interpolated signal and a temporally interpolated signal in accordance with the estimated motion decision value.

Specific information with regard to the interpolation of interlaced video signals and interlaced to progressive conversion is readily available to those of skill in the pertinent art. The above-noted disclosures, namely U.S. Patent Nos. 5,943,099 and 5,959,681, are specifically incorporated by reference.

Some examples of the spatially interpolated signal $x_n^s(v,h)$ are

$$x_n^s(i,h) = (x_n(i-1,h) + x_n(i+1,h))/2$$

which corresponds to a line average and

$$x_n^s(i,h) = x_n(i-1,h)$$

which corresponds to a method known as line doubling.

Also, some examples of temporally interpolated signal $x_n^t(v,h)$

$$x_n^t(i,h) = (x_{n+1}(i,h) + x_{n-1}(i,h))/2$$

and

$$x_n^t(i,h) = x_{n-1}(i,h) \, .$$